

## **A “REDUCED-NOISE GAS FLOW DESIGN GUIDE” FOR NASA GLENN RESEARCH CENTER**

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### **INTRODUCTION**

A “Reduced-Noise Gas Flow Design Guide” (*Design Guide*) has been developed for NASA Glenn Research Center (GRC). A wide variety of gas flow experiments and apparatus are designed and utilized at GRC in its research programs. Because of the power of many of these systems, hearing conservation and community noise are important issues. The purpose of this Guide is to allow GRC engineers and designers to address noise emission at the design stage using readily available system parameters. Although the Guide was developed with GRC equipment and systems in mind, it is expected to have wide application in more general industrial applications.

The *Design Guide* consists of two parts: a written “Manual” and a Microsoft Excel® “Workbook”. The Manual explains mechanisms of noise generation, provides low-noise design guidelines, lists design parameters required for noise estimation, and describes applicable noise control methods. Closed-form algebraic equations are provided that estimate noise emission. The noise emission estimates are implemented in an easy-to-follow spreadsheet format in the accompanying software Workbook.

## **SCOPE AND APPLICATION**

The User need not have formal training in acoustics, but some degree of familiarity with acoustical concepts such as frequency, sound pressure level, octave- and A-weighted filtering, etc. is presumed.

Noise-generating gas flow processes that are addressed include:

- Gas and steam discharge vents, ambient air intake vents, inlet debris screens,
- Compressors, exhausters, fans and blowers,
- Turbomachinery components: inlet fan and compressor, combustor core, turbine, exhaust jet mixing and exhaust jet shock cells,
- Flow noise from pipe walls and at fittings,
- Control valves,
- Orifices and venturis.

Noise control performance of elements typically associated with gas flow systems are also addressed:

- Walls of pipes, ducts and vessels
- Vent silencers and in-line silencers,
- Intake and discharge duct openings, with flow
- Acoustical lagging

## **MANUAL**

The Manual explains prudent design practices for reducing noise in words, graphics and equations. It describes methods of estimating noise emission for a wide variety of gas flow noise sources as well as the benefit of common noise-reducing elements.

Noise emission estimation equations were adapted from sources in the open literature. Extensive references are provided. No empirical factors are required that would have to be derived from acoustical experiments. Parameters of the predictive equations consist of readily available design information such as mass flow rates, gas properties, pipe diameter and wall thickness, etc. No hand calculations are necessary: the accompanying Workbook implements the engineering equations described in this text.

## **WORKBOOK**

The Workbook consists of sixteen spreadsheets that implement the noise emission and noise reduction estimates, two spreadsheets that perform computations for an elementary gas flow system, and a handy gas flow parameter calculator spreadsheet (unit conversions, dB mathematics, ideal gas equations, isentropic expansions and contractions, etc.).

Spreadsheets have a fill-in-the-blanks format and guide the user through entering the relevant input parameters. The User selects units for input and output by means of drop-down lists. Units may be mixed without restriction.

Noise emission from a gas flow system is modeled using two linked spreadsheets that combine estimates for the individual components using the “cut and paste” method. The gas flow system addresses radiation from pipe openings, pipe walls and extended surfaces, the benefit of in-line silencers, and the influence of reverberation on indoor sound levels.

Noise emission estimates are compared directly with a Maximum Permissible Sound Level (MPSL) value entered by the User and with a GRC-specific sound power level limit spectrum applied to outdoor equipment. These criteria are determined from the NASA GRC “Guide for Specifying Equipment Noise Emission Levels” (*Specifications Guide*)<sup>i,iii</sup>. Octave band values that approach or exceed the criteria are denoted by a color-coding scheme.

### **INDIVIDUAL COMPONENT SPREADSHEETS**

The first two figures provides excerpts from a typical noise emission spreadsheet as it appears on an 800 x 600 pixel computer display. Figure 1 displays a portion of the Spreadsheet containing primarily User inputs, while Figure 2 displays a section containing primarily outputs. Cells requiring input have a black border and white background. Cells containing computed results are shaded in blue. A supplemental color-coding scheme is used where results are compared to criteria. For octave band and A-weighted results that approach the criterion, the cell background color changes to orange; if the results exceed the criterion, the cell background color changes to red.

As an example of typical inputs, Control Valve noise emission is estimated from the Gas molecular weight and compressibility factor, mass flow rate, pressure upstream and downstream of valve, upstream temperature, valve type and  $C_V$ , valve nominal diameter, upstream and downstream pipe diameter and pipe wall thickness.

### **GAS-FLOW SYSTEM SPREADSHEETS**

Special considerations arise when considering noise emission from a gas-flow system. Noises produced by one component (e.g., a compressor) may radiate most strongly from other segments of the system (e.g., inlet opening or piping). An elementary model gas flow system has been developed that includes the following elements:

- ✓ A group of up to six “Equipment” items centrally located in the system. Intake, discharge and casing sound power levels are tabulated separately.
- ✓ An optional enclosure or building housing the equipment. General sound-absorptive properties of the enclosure may be specified.
- ✓ Intake and discharge piping connected to the equipment. Some of this piping may be specified as being located outside of the enclosure. The ends of the piping may be designated as “open” or “closed” to the atmosphere.

- ✓ Intake and discharge silencers located within the enclosure, including silencer self-noise.
- ✓ An indoor “Equipment Observation Position” whose location may be specified
- ✓ An “Outdoor Observation Position” whose location may be specified

A diagram of the model system is provided in Figure 3.

Row	Column A	Column B	Column C	Column D	Column E	Column F	Column G	Column H	Column I	Column J	Column K	Column L	Column M	Column N
6	<b>1. Select Flow Conditions</b>													
8	1a. Gas	Nitrogen (N2)												
9	Specific Gravity	0.97	[1]				G							
10	Ratio of Specific Heats	1.40	[1]				$\gamma$							
11	1b. Gas Compressibility Factor	1	[1]				Z							
12	1c. Mass Flow w [lbs/sec]	225	[lb/sec]				$m'$							
13	1d. Upstream Pressure	4	[atm]				$P_1$							
14	1e. Upstream Temperature	200	[° R]				$T_1$							
15	1f. Downstream Pressure	14.7	[psia]				$P_2$							
17	<b>2. Select a Candidate Valve Type, Perform Approximate Sizing</b>													
19	2a. Select Valve Type													
20	Type: Butterfly valve, swing-through vane, Flow To: N/A, Travel: 75° open													
23	Flow is	Sonic												
24	Approx. $C_v$ required	5592				$C_v$	(Iterate with Line 3.a)							
25	Approx. $D_v$ required	13.2	[in]			$D_v$	(Iterate with Line 3.b-3.d)							
26	Approximate $C_v$ Wide Open	8176				$C_v$								
28	<b>3. Make Valve and Pipe Selection</b>													
30	3a. Select C	3100	[Cv]											

**Figure 1: Typical Individual Component Spreadsheet Inputs**

The System Input/Output spreadsheet (see Figure 4) manages noise emission and noise control data for the model system. The User provides information on the geometry and configuration of the system, noise criteria expressed as Maximum Permissible Sound Level (A-weighted sound pressure level) criteria for various locations, and upstream, downstream and casing sound power level data from individual system components. The data are “cut and pasted” by the User into appropriate Input cells.

A-weighted sound pressure level and sound power level estimates for the system are also displayed in the System Input/Output spreadsheet. The results are color-coded as described above based on a comparison of criteria with the estimated noise emission. The details of the noise emission model computations are displayed on the “System Calculations” spreadsheet.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
39	Pipe First Mode Cut-on Freq.	813 [Hz]					$f_c$							
40	Pipe Ring Frequency	3164 [Hz]					$f_r$							
41	Internal Overall PWL	160 dB $L_W$					$L_W$							
42	Structural Limit Overall PWL	164 dB $L_W$					$L_{WS}$							
43	Internal PWL - Structural Limit	-3 dB $L_W$												
44														
45	<b>5. Estimated Noise Emission</b>													
46														
47	<b>5a. Calculate Octave Band Sound Pressure Levels 1m from Pipe</b>													
48		31.5	63	125	250	500	1000	2000	4000	8000				<b>A</b>
49	Internal $L_p$	153	157	162	163	159	156	152	149	145				<b>162</b>
50	Pipe TL	67	61	55	49	43	40	44	46	51				
51	$L_g$	3	3	3	3	3	3	3	3	3				
52	$L_p$ at 1 m from Pipe Centerline	89	99	<b>110</b>	<b>117</b>	<b>119</b>	<b>118</b>	<b>111</b>	<b>105</b>	<b>97</b>				<b>121</b>
53	<b>Maximum Permissible Sound Level (MPSL) for Control Valve</b>													
54														<b>95</b>
55	<b>5b. Add the Benefit of Control Valve Noise Control Options</b>													
56														
57		<input checked="" type="checkbox"/> Valve Trim	<input type="checkbox"/> Downstream Valve Silencer	<input type="checkbox"/> Upstream Valve Silencer	<input checked="" type="checkbox"/> Downstream Resistance Plate									
58	<b>Sound Pressure Level (<math>L_p</math>) at 1 m</b>	31.5	63	125	250	500	1000	2000	4000	8000				<b>A</b>
59	$L_p$ at 1 m from Pipe Centerline	89	99	110	117	119	118	111	105	97				<b>121</b>
60	Insertion Loss of Selected Noise Control	25	25	25	25	25	25	25	25	25				
61	$L_p$ 1 m from Pipe CL, Noise Control	64	74	85	92	<b>94</b>	<b>93</b>	86	80	72				<b>96</b>
62														<b>MPSL for Control Valve 95</b>

Figure 2: Typical Individual Component Spreadsheet Outputs

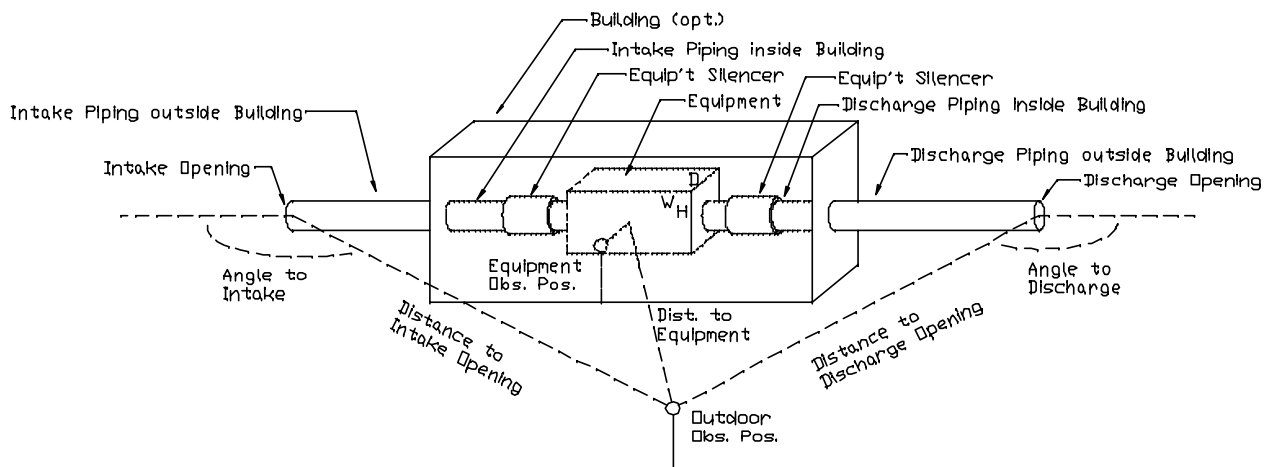


Figure 3: Model Gas-Flow System

File Edit View Insert Format Tools Data Window Help											Close Full Screen	
	A	B	C	D	E	F	G	H	I	J	K	L
57	3. System Criteria and Overall Results*											
58												
59	3a. Maximum Permissible Sound Pressure Level (MPSL)											
60	Intake		Criterion			L <sub>p</sub> Estimate		L <sub>w</sub> Estimate				
61	Intake Opening at 1 meter		N/A	dB(A) L <sub>p</sub>		0	dB(A) L <sub>p</sub>	0	dB(A) L <sub>w</sub>		Criteria	
62	Outdoor Intake Piping at 1 meter		85	dB(A) L <sub>p</sub>		86	dB(A) L <sub>p</sub>	112	dB(A) L <sub>w</sub>		Criteria	
63	Indoor Intake Piping at 1 meter		100	dB(A) L <sub>p</sub>		99	dB(A) L <sub>p</sub>				Criteria	
64	OK RE STRUCTURAL CRITERION											
65	Discharge											
66	Discharge Opening at 1 meter		N/A	dB(A) L <sub>p</sub>		0	dB(A) L <sub>p</sub>	0	dB(A) L <sub>w</sub>		Criteria	
67	Outdoor Discharge Piping at 1 meter		85	dB(A) L <sub>p</sub>		86	dB(A) L <sub>p</sub>	112	dB(A) L <sub>w</sub>		Criteria	
68	Indoor Discharge Piping at 1 meter		100	dB(A) L <sub>p</sub>		99	dB(A) L <sub>p</sub>				Criteria	
69	OK RE STRUCTURAL CRITERION											
70												
71	3b. A-weighted Sound Pressure Level Targets											
72	Desired A-wt. Sound Pressure Level at Outdoor Observation Position											
73	All Outdoor Openings, Piping, Equipment		66	dB(A) L <sub>p</sub>		64	dB(A) L <sub>p</sub>				Criteria	
74												
75	Desired A-wt. Sound Pressure Level at Indoor Observation Position											
76	Equipment and Indoor Piping		100	dB(A) L <sub>p</sub>		102	dB(A) L <sub>p</sub>				Criteria	
77	* CONSULT THE SYSTEM CALCULATIONS SHEET FOR DETAILED COMPUTATIONS AND INTERMEDIATE RESULTS											
78												
79												

**Figure 4: System Input/Output Spreadsheet**

## CONCLUSION

A “Reduced-Noise Gas Flow Design Guide” has been developed for NASA Glenn Research Center. The Guide comprises two parts, a written Manual and a Microsoft Excel®-compatible Workbook, and is intended to assist with noise emission estimates early in the equipment design phase. Although the Guide was developed with GRC equipment and systems in mind, it is expected to find wide application in more general industrial applications.

<sup>i</sup> David A. Nelson, *Guide to Specifying Equipment Noise Emission Levels*, Hoover & Keith, Inc. under contract to NASA Glenn Research Center, 1996. This Guide may be obtained from the Noise Exposure Management Program ((216) 433-3950, or via [http://www-osma.grc.nasa.gov/oep/nmtpages/oep\\_nt.htm](http://www-osma.grc.nasa.gov/oep/nmtpages/oep_nt.htm))

<sup>ii</sup> Cooper, Beth A. and Nelson, D. A., *Implementation of a “buy-quiet” policy for equipment purchases at the NASA Lewis Research Center*, Proceedings of Noise-Con 97 and J. Acoust. Soc. Am., Vol. 101, No. 6, June 1997.